Autonomous Firefighting Drone
Final Report

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Executive Summary

Team 1801 and its engineering project was sponsored by Sikorsky to design and build an autonomous firefighting drone. We initially designed a drone to seek out a fire while avoiding obstacles and then put out a flame using a water propellant system. Each member of the team worked on a specific subsystem to complete the project. A customizable octocopter was built and equipped with obstacle sensors, heat sensors, and a fire extinguisher. The drone used a Pixhawk flight controller which worked side by an Arduino, a programmable microcontroller responsible for non-flight related tasks. By the end of the yearlong project, we developed a working prototype that was able to put out a small flame using the flame detection and water propulsion system.

Statement of Need

Every year firefighter pilots risk their lives to help extinguish forest fires using specially designed aircraft. These aircraft deliver a payload of fire retardant to reduce the flames. Unfortunately, the missions may result in accidents or may fail to effectively fight the fires. An unmanned, autonomous aircraft that can detect and extinguish flames would reduce the death of pilots and increase the chance of putting out fires.

Our objective is to customize a commercially available UAV to demonstrate autonomous obstacle avoidance in flight, while carrying a payload of water to be used in extinguishing a flame. The flight control system and flame detector should be scalable to a larger aircraft capable of fighting forest fires.

Background

Aside from military and transportation purposes, helicopters are used for fire aviation to deliver a payload of fire retardant. However, helicopters operated by pilots run the risk of becoming distracted, incapable of operating the drone/vehicle, or being unable to avoid an incoming obstacle. Therefore situations like these might cause helicopters to become damaged and lead to casualties without accomplishing the objective to extinguish the fire. In order to eliminate these obstacles and increase the efficiency of fighting fire, we can integrate autonomous features of both obstacle avoidance and fire-fighting capabilities into the helicopter.

Over the recent years, the usage of drones has increased greatly both for military and commercial use. We plan on modifying a commercially available drone with an autonomous obstacle avoidance system and firefighting system to be used as a small scale version of a helicopter for future use.
**Design Approach**

The approach to picking the drone that was the best fit for this project was done through careful revision of each for the drone features. Table 1 below gives an overview of the trade study. After scouring the internet for a drone that would be the perfect fit, we were able to narrow our options down to two choices: the Tarot T-15 and the DJI- S1000. We also included last year team’s drone 3DR IRIS+ in the table for comparison purposes. The main reason why we can eliminate last year's drone can be seen from the first column alone where the payload is only 0.4 kg. This is nearly not enough for all the sensors along with the water propellant system. This still leaves the Tarot T-15 and the DJI- S1000. The next row displaying the price shows where the T-15 starts to look a lot better than the S1000. The T-15 is only $924 where the S1000 eats up half of the budget with a whopping $1500 price tag. Furthermore the T-15 allowed for more flight control integration systems as well as a bigger diagonal wheelbase allowing for more room for sensors and water propellant system integration.

<table>
<thead>
<tr>
<th>Drone</th>
<th>3DR IRIS+ (Previous Team)</th>
<th>Tarot-T15</th>
<th>DJI-S1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payload(kg)</td>
<td>0.4</td>
<td>8</td>
<td>14</td>
</tr>
<tr>
<td>Price(USD)</td>
<td>449</td>
<td>924</td>
<td>1500</td>
</tr>
<tr>
<td>Material</td>
<td>Zytel Nylon</td>
<td>Carbon Fiber</td>
<td>Carbon Fiber</td>
</tr>
<tr>
<td>Type of UAV</td>
<td>Quadcopter</td>
<td>Octocopter</td>
<td>Octocopter</td>
</tr>
<tr>
<td>Flight Control Integration</td>
<td>Pixhawk</td>
<td>Pixhawk, Quadrino NANO and more</td>
<td>A3</td>
</tr>
<tr>
<td>Diagonal Wheelbase (mm)</td>
<td>551.2</td>
<td>1100</td>
<td>1045</td>
</tr>
</tbody>
</table>

Table 1. Comparison Chart of Commercially Available Drones

In addition, we found a couple of sensors that would aid us with proximity sensing. In Table 2 below, we have a comparison chart of our findings. At first, we considered using 8 ultrasonic sensors on each arm of the drone, but we calculated that there will be blind spots in this configuration. We chose the Sweep V1 due to a better range, angle and ability to perform outdoors.
<table>
<thead>
<tr>
<th>Proximity Sensors</th>
<th>RPLidar A1M8</th>
<th>HCSR04 Ultrasonic</th>
<th>Sweep V1 360 Lidar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection Range (m)</td>
<td>6</td>
<td>4</td>
<td>40</td>
</tr>
<tr>
<td>Sampel Rate (KHz)</td>
<td>2</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>Power Supply (V)</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Angle (Degrees)</td>
<td>360</td>
<td>15</td>
<td>360</td>
</tr>
<tr>
<td>Number of Sensors Needed</td>
<td>1</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Price (USD)</td>
<td>199</td>
<td>4 each</td>
<td>350</td>
</tr>
</tbody>
</table>

Table 2. Comparison Chart for proximity sensors.

**Specifications**

The copter needs to be an autonomous drone that uses sensors to detect the location of a fire. The drone should approach the fire utilizing its sensory feedback system and avoid any obstacles in its course. After reaching the location of the fire, the drone must use its water propulsion system to extinguish the fire. Sikorsky also requested that we complete a System Requirements Specification (SRS) and an Engineering Test Procedures (ETP). A demonstration of the working project utilizing the ETP is also required during Senior Design Day to validate the SRS.
Timeline and Milestones

Our timeline and milestones for the Fall 2017 and Spring 2018 semesters can be seen below.

Description of Design

Our firefighting drone will encompass important autonomous features which include obstacle avoidance, flame detection, and firefighting utilizing a water propulsion system. These three features will be implemented on a commercially available octocopter, the Tarot T15, which will be running the Pixhawk flight controller, and a Raspberry Pi microcontroller to assist the readings. In Figure 1 below, we have a block diagram of how all these peripherals will connect with the flight controller. The blue blocks represent parts of the commercially available drone while the red blocks represent the systems we plan to integrate with the drone.
Commercial Unmanned Aerial Vehicle

The base of this project is in choosing a unmanned aerial vehicle that can lift a large payload, easy flight controller integration, and is within our budget. We chose the Tarot T15 because of these parameters. The Tarot T15 is compatible with the Pixhawk flight controller already equipped with 3-axis gyroscope and accelerometer, magnetometer, and barometer. The Pixhawk can also connect to external peripherals to implement additional features to the system. The Pixhawk runs on a free, open source, flight control software called Ardupilot. We will be using Ardupilot to implement the obstacle avoidance system along with the flight control system.

Another device that we plan to integrate with the Pixhawk is the Arduino, a small programmable microcontroller. Like the Pixhawk, the Arduino can connect to external peripherals such as sensors or servos. The main benefit of using a separate computer is that we can offload non flight related tasks to the Arduino. The Pixhawk will be using most of its resources to maintain consistent, stable flight. Meanwhile, we plan to implement the flame detection and water propulsion system in the Arduino.

Figure 1. Block Diagram of the Firefighting Drone
Proximity Sensing

The obstacle avoidance system will consist of a 360° light detection and ranging (LIDAR) sensor, the Sweep V1. The Sweep V1 will be placed flat, on top of the Tarot T15, to cover the maximum possible area without interference from parts of the drone. The Sweep V1 will be connected to the Pixhawk as an external peripheral. This sensor has a maximum operating range of 160 ft. and provides up to 1000 samples per second. The rotational frequency of the sensor can be adjusted between 2-10 Hz which affects the resolution of the data. We plan to fix the rotational frequency at 3 Hz so that we can receive about 1 sample per degree of field of view. This will allow the system to easily detect small (1 ft.) objects within 20 feet of the drone. The obstacle avoidance system will prevent further movement towards a stationary object when said object is found within 2 feet of the drone.

Flame Detection

The flame detection system will utilize a thermopile array sensor, the TPA81, to obtain temperature readings from objects at a distance. The TPA81 consists of an array of 8 thermopiles or pixels. The TPA81 can measure the temperature from each pixel simultaneously. Each pixel has a field of view of 5.12° by 6°. In total, the sensor has a field of view of 41° by 6°. Therefore, the effective distance of the sensor is only limited by the size of the object which you are measuring the temperature from. For example, a flame the size of a foot is easily detectable by a single thermopile from a distance of 11 feet. The flame detection system will also consist of an ultrasonic sensor HC-SR04 to detect the distance of the drone to the object on fire. The HC-SR04 has an effective range of up to 13 feet which also limits our flame detection system to 13 feet. Both the TPA81 and HC-SR04 will be oriented at a 45° from the horizon aligned to the front of the drone. The fixed position of the sensors will allow us to easily calculate the position of the drone relative to the flame. Once the system has detected a flame within its vicinity, the drone will approach the flame so that its water propulsion system has a direct line of fire.

Flame Extinguisher

The water propulsion system will consist of a small refillable fire extinguisher and a servo that pulls the lever to the extinguisher. The extinguisher will be mounted horizontally underneath the body of the drone to evenly distribute the weight and provide a stable flight. The exhaust pipe of the extinguisher will be pointed at a 45° from the horizon just like the flame detection system. The fire extinguisher will be activated upon two conditions. First, a flame has to be detected and a constant line of sight will be required. Second, the drone must be positioned about 2-3 feet away from the flame so that the exhaust tube of the extinguisher is pointed directly at the flame. Once the entire content of the extinguisher is used, the drone will fly back to its starting location which is recorded using GPS coordinates.
**Flight Control Software**

Ardupilot is a free open source flight control software compatible with our Pixhawk flight controller. Ardupilot is a great choice for this project because we want to develop a custom flight mode that can autonomously take off, hover, search for a flame, and land. The Ardupilot software can be built and edited using the Eclipse IDE. After creating a custom flight mode and integrating the flight mode with the rest of the flight modules, we can build the firmware to be uploaded onto the Pixhawk.

Mavlink, or Micro Air Vehicle Link, is a protocol used for communication between the Arduino and the Pixhawk flight controller. Mavlink is useful because it allows the Arduino to perform calculations based on its sensors and provide real time commands to the flight controller. The goal was to use the input from fire detection system to align the nozzle of the fire extinguisher to the flame. The messages sent using Mavlink is done through packets and each packet has an ID field on it. The sequence of the message is as follows: first the start-of-frame is sent which signifies the start of the frame transmission. Next, the payload length is send which is then followed by the packet sequence, the system ID, component ID and message ID. After all of this, the payload is sent followed by the CRC, or the Cyclic Redundancy Check. This used as an error detecting method to check for accidental changes in the raw data.

**Budget**

The provided budget for this project is $3000. Considering everything, including the drone itself, had to be included in this price range, the process of picking the components for the project was very meticulous and thorough. After careful collaboration with everyone from the team, we finally chose all our components for this project including choosing the Tarot-T15 Octocopter as our drone. The entire budget breakdown can be seen below:
<table>
<thead>
<tr>
<th>Vendor</th>
<th>Material</th>
<th>Description</th>
<th>Cost</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hobbywing</td>
<td>Tarot T15 Combo Kit</td>
<td>Includes frame, motors, escs, and propellers (include connectors and plugs for wiring)</td>
<td>924</td>
<td>1</td>
</tr>
<tr>
<td>Hobbywing</td>
<td>Pixhawk + M8N GPS SE100 Combo</td>
<td>Flight controller + GPS module</td>
<td>129</td>
<td>1</td>
</tr>
<tr>
<td>Hobbywing</td>
<td>Tarot T1555</td>
<td>Propellers</td>
<td>10.99</td>
<td>2</td>
</tr>
<tr>
<td>Hobbywing</td>
<td>FrSky Taranis Q X7</td>
<td>16 CH Transmitter (Radio controller)</td>
<td>109</td>
<td>1</td>
</tr>
<tr>
<td>Hobbywing</td>
<td>FrSky X4RSB 3/16ch Telemetry Receiver</td>
<td>16 CH Receiver</td>
<td>26.99</td>
<td>1</td>
</tr>
<tr>
<td>RobotShop</td>
<td>Lidar-Lite 3 Laser Rangefinder</td>
<td>Lidar sensor underneath drone</td>
<td>119.67</td>
<td>1</td>
</tr>
<tr>
<td>RobotShop</td>
<td>Sweep V1 360</td>
<td>360 lidar</td>
<td>349</td>
<td>1</td>
</tr>
<tr>
<td>RobotShop</td>
<td>Thermal Array Sensor</td>
<td>Temperature sensor</td>
<td>70</td>
<td>1</td>
</tr>
<tr>
<td>Venom Power</td>
<td>Tarot T15 15C 6S 16000mAh 22.2V LiPo</td>
<td>LiPo battery</td>
<td>339.99</td>
<td>1</td>
</tr>
<tr>
<td>Helipal</td>
<td>Landing Skids T-Joint</td>
<td>Plastic T-Joint</td>
<td>7.99</td>
<td>4</td>
</tr>
<tr>
<td>Helipal</td>
<td>Aluminum Quick-release</td>
<td>Metal T-Joint</td>
<td>11.99</td>
<td>2</td>
</tr>
</tbody>
</table>

This leaves about $910 from the total budget that will be needed to address the AA batteries for the radio controller, all the components for the water propellant system, as well as any spares that may be needed. This part of the budget is labeled as unallocated for now. In order to give a better understanding our spending, a pie chart of the budget breakdown is given below:
Results

Our project was broken down several key phases. After completing the design of our drone toward the end of the first semester, we began to build the drone after acquiring the necessary hardware. The drone was completed at the end of the first semester but we were unable to start test flights until the winter weather had passed. High gusts of wind and cold temperatures made it unsuitable for inexperienced pilots to begin test flights. Test flights began indoors at the end of February to verify that the drone could lift off but we quickly realized that indoor flight was dangerous for a large octocopter. Starting March, we were able to start test flights and diagnose various calibration and wiring issues with the drone. By mid-March, we had a fully functional octocopter.

While test flights were occurring, we developed the software necessary for flame detection and the water propulsion system. We used an Arduino to begin testing the sensors because the Arduino provided much easier access to writing and testing the software. Following our initial design, we used a TPA-81 thermopile array sensor and HC-05 sonar sensor to detect a flame and the distance of the flame to the sensors. We were able to detect small flames up to 3 meters away from the sensor. An important thing to realize was that in order to detect a flame at a farther distance, we needed a larger flame due to the area the sensors covers at large distances. We then integrated a servo with the system to activate the servo upon detecting a flame at a distance of 3 meters. The servo would then wind up a wire to pull the lever of a fire extinguisher.

We also began developing a custom flight mode and added it to the Ardupilot flight controller software. We were able to arm the copter through the custom flight mode and develop the necessary logic for performing tasks such as autonomous take off, landing, and hover hold but we were held back by our lack of knowledge on the flight controller libraries. Using the correct library and its functions is mandatory in order to build the firmware without compilation errors.
We were also able to establish communication between a Raspberry Pi and the Pixhawk through the Mavlink communication protocol. We used the Pi instead of an Arduino for this part of the project because Mavlink was much easier to work with using a Linux based system. Additionally, the Pi had far more support in the drone community than the Arduino. Basic commands like arming the copter, changing flight modes, and receiving information about the state of the drone was achieved through Mavlink.

Conclusion

Although this was a very challenging project, we gained tremendous knowledge about drones, flight controllers and their complicated software and sensory feedback systems. Best of all, we had the chance to fly the drone and experience the thrill of seizing the skies. The largest constraint for this project though, was the lack of time we had due to circumstances beyond our control such as the weather and time lost to repairing damages to the drone after crashes. Many of our crashes were attributed to our lack of knowledge on flying a drone but, once we got the hang of it, crashes occurred less.

Some recommendations for the future team working on this project would be to continue the development of the autonomous flight mode using Ardupilot and Mavlink. Autonomous take off, hover hold, and landing would be very beneficial so that the pilot would have minimal responsibilities for the flight of the drone. Additionally, an autonomous scanning technique to detect a flame would be a tremendous improvement to our progress. With the addition of these recommendations, one would be able to deploy the drone without touching the controller. Finally, we were unable to complete the obstacle avoidance system. We were able to integrate the 360 Lidar sensor but we did not have the time to complete the software.

Personnel and Collaborators

Our team was comprised of three electrical engineering majors and one computer engineering major. We have a strong background in many different areas such as control systems and communication systems. Supporting our team was our faculty advisor, Ashwin Dani. He provided suggestions from technical and theoretical aspects. The representative from Sikorsky was Jason Thibodeau, who has helped us stay on track with the requirements of the project and monitored our progress though weekly meetings.